PLASMA PROCESSING OF LARGE SURFACES WITH APPLICATION TO SRF CAVITY MODIFICATION

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Abstract

Plasma based surface modification is a promising alternative to wet etching of superconducting radio frequency (SRF) cavities. The crucial aspect of the technology development is dependence of the etching rate and surface roughness on the frequency of the power supply, pressure, power level, driven electrode shape and chlorine concentration in the gas mixture during plasma processing. To optimize the plasma parameters, we are using a simple cylindrical cavity with 8 sample holders symmetrically distributed over the cylinder. These holders are used as diagnostic ports for the measurement of the plasma parameters and as holders for the samples to be etched. The plasma properties are highly correlated with the shape of the driven electrode, chlorine concentration in the Argon/Chlorine gas mixtures, residence time of reactive species and temperature of the cavity. Using cylindrical driven electrodes with variable radius, we have optimized the plasma properties with respect to surface maximum processing effect.

INTRODUCTION

To improve the RF performance of the SRF niobium cavities, the cavity surface must be prepared by a process that enhances surface smoothness, removes impurities and create less sharp grain boundaries. Currently used technologies are buffered chemical polishing or electro polishing. These technologies are based on the use of hydrogen fluoride (HF) in liquid acid baths, which poses major environmental and personal safety concern. HF-free plasma-based ("dry") technologies are a viable alternative to wet acid technologies as they are much more controllable, less expensive and more environment-friendly.

As a proof of concept we developed an experimental setup for etching of small niobium samples [1]. The microwave plasma (2.45 GHz) frequency inside a quartz tube was used for this experiment. The gas mixture used was 97% argon and 3% chlorine. While the results with the flat samples were very encouraging [1], with etching rates up to 1.7 µm/min and surface roughness down to below 100 nm, the two parameters could not be achieved with the same treatment. Results are indicative of competitive character of the surface smoothness and etching rate. In every case, however, the surface roughness of plasma etched sample is equal or better than the chemically etched samples. The next step in the development of plasma etching technology for SRF cavity is to perform the etching of a single cell niobium cavity on optimized plasma parameters. We are here describing an intermediary step where a curved Nb surface substantially larger than the flat coupon area was successfully processed at a satisfactory rate at a relatively modest power level.

CYLINDRICAL CAVITY EXPERIMENT

The shape of the cavity is defined by the resonant low-loss requirement for maximizing the cavity Q factor and generating the accelerating gradients at microwave frequency of 1.5 GHz.

Before etching the cavity, we developed an experiment with simple cylindrical cavity of 2.86 inch internal diameter and 6 inch length. This cylindrical cavity has 8 holes with mini conflat welded on it to hold niobium samples and to put view port for diagnostic purposes. The cavity is shown in the Figure 1.

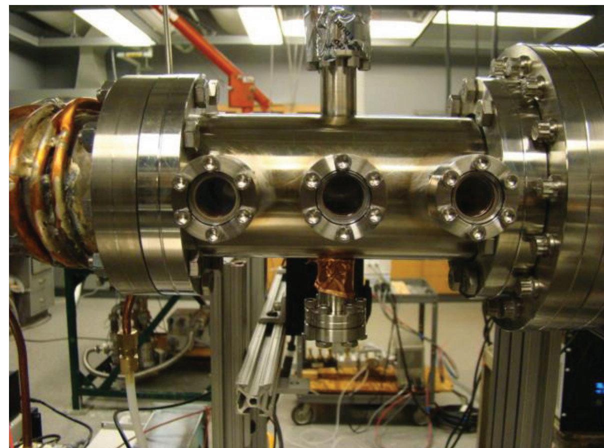

Figure 1: Cylindrical cavity on processing experiment.

Although we are planning to use two frequencies, one in the radio-frequency (RF) and the other in the microwave (MW) range to produce plasma inside this cavity, we are currently using is RF at 13.56 MHz In the RF case the EM wavelength is approximately 22 meter in the case of 13.56 MHz and much longer than the cavity length while in the MW case the wavelength is in the same scale as the cavity length.

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In the first case, when we are using a RF power supply, the plasma produced is in the capacitively coupled plasma (CCP) regime. In CCP the difference in surface area of driven and grounded electrode creates a difference in voltage drop of two sheaths established on both electrodes.

Shape of SRF cavity presents a particular challenge for RF plasma processing of its inner wall. It has curved cylindrical symmetry and the processed surface has larger area than the surface of the driven electrode. By contrast, the technology that has been in the mature stage of development, such as semiconductor wafer processing, is based on essentially planar geometry. Moreover, the wafer which is etched presents the smaller-area electrode in order to take advantage of the asymmetry in the plasma sheath voltage. In present case the cavity which is to be etched is grounded and has large surface area.

To learn more about the asymmetry of the cylindrical RF discharge, we opted for a variable diameter of inner electrode looking for the effect of the surface area of inner electrode on plasma properties. A set of variable diameter electrodes with the experimental cylindrical cavity is shown in Figure 2.

Figure 2: Cylindrical cavity with different diameter electrode.

The criterion for chosing the optimum electrode was provided by a set of plasma parameters that was measured using a Langmuir probe, a high precision scanning monochromator. In addition, the gas composition was determined with a high pressure residual gas analyser.

The experimental setup for the cylindrical cavity processing is shown in the Figure 3. The cylindrical chamber is evacuated with the help of combination of rough and turbo vacuum pump. The gas flow and electrical power flow are in opposite direction. Gas was premixed in three-branch manifold, each branch containing flow controllers, which defined the mixing ratio. The mix was dominated by Argon and Helium as buffer gases, and Chlorine.

Figure 3: Experimental setup for plasma processing of cavities.

As the plasma properties and in turn the surface processing effect vary substantially with the frequency, pressure, chlorine concentration, temperature and power levels inside the reactor, we have to optimize these parameters for the most efficient and uniform surface material removal from the samples placed on the cavity perimeter.

EXPERIMENTAL RESULTS

Depending on the diameter of the driven electrode tube there is a certain pressure on which the plasma is completely filled in the cavity. If you operate cavity below this pressure the plasma is only in certain section. The plasma inside the cavity at different pressure is shown in Figure 4.

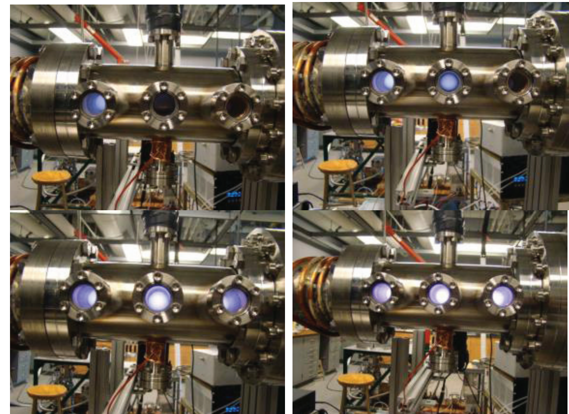

Figure 4: Plasma inside the cylindrical cavity at different pressure.

We have established a scheme of Ar I levels in order to follow the effects of plasma etching conditions on the excited state balance and produce the foundation for the arguments on the optimum plasma etching conditions. The levels are grouped in blocks, which are represented with an average energy. Spectral line intensities expressing transition from the levels belonging to each block to 4p or 4s levels are strongly dependent on plasma parameters and indicate the decline of excited state

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population during material removal from the surface. We correlated the removal of material from the surface with the line intensity variation and found the easily observed "sweet spots" in external discharge parameters. In what follows all spectra were taken through the side windows of the discharge cell, across the sheath layer, and can be correlated to the average energy of electrons that are being accelerating through the sheath and that are responsible for reactive ion and radical production. Pressure dependence of the intensity ratio of several 5p-4s Ar lines is illustrated in Figure 5.

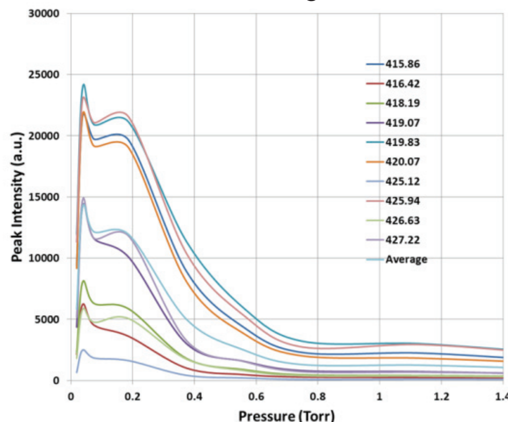

Figure 5: Intensity of Argon line versus pressure.

Figure 5, the Pressure dependence of the intensities of Ar I 5p-4s lines indicate the reduction of electron density with pressure due to increased electronegativity and presence of removed volatiles from the surface. RF power was 100 W, and the mix composition by weight was Ar/Cl_2 (85/15).

CONCLUSION

In view of the complex technological challenges facing the development of plasma-assisted SRF surface treatment, we have adopted the following experimental approach: (a) to determine and optimize the plasma condition suitable for the uniform mass removal and optimum surface smoothness for the samples placed on the simple cylindrical cavity perimeter, (b) to process a single-cell cavity at established optimum conditions for discharge in the cavity geometry, and (c) to perform RF performance tests compatible with existing standards. In both experiments, the central electrode (RF) and antenna (MW) is used to control the breakdown of the large-volume plasma and to assure its uniformity.

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